UTILITY ADVANCED TURBINE SYSTEMS PROGRAM (ATS)

TECHNICAL READINESS TESTING AND

PRE-COMMERCIAL DEMONSTRATION

CONTRACT NO. DE-FC21-95MC32267

FINAL

QUARTERLY TECHNICAL PROGRESS REPORT TPR-20
For the Period January 1, 2001 to March 31, 2001

to the

U.S. DEPARTMENT OF ENERGY

Office of Fossil Energy

National Energy Technology Laboratory

Morgantown, West Virginia

August 17, 2001

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ABSTRACT

The objective of the ATS program is to develop ultra-high efficiency, environmentally superior and cost competitive gas turbine systems for base load application in utility, independent power producer and industrial markets. Specific performance targets have been set using natural gas as the primary fuel:

- System efficiency that will exceed 60%(lower heating value basis) on natural gas for large scale utility turbine systems; for industrial applications, systems that will result in a 15% improvement in heat rate compared to currently available gas turbine systems.
- An environmentally superior system that will not require the use of post combustion emissions controls under full load operating conditions.
- Busbar energy costs that are 10% less than current state-of-the-art turbine systems, while meeting the same environmental requirements.
- Fuel-flexible designs that will operate on natural gas but are capable of being adapted to operate on coal-derived or biomass fuels.
- Reliability-Availability-Maintainability (RAM) that is equivalent to the current turbine systems.
- Water consumption minimized to levels consistent with cost and efficiency goals.
- Commercial systems that will enter the market in the year 2000.

In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plant is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design.

This report summarizes Phase III extension activities for a three month period. Additional details may be found in monthly technical progress reports covering the period stated on the cover of this report. Background information regarding the work to be completed in Phase III may be found in the revised proposal submitted in response to A Request for Extension of DE-FC21-95MC32267, dated May 29, 1998 and the Continuing Applications of DE-FC21-95MC32267, dated March 31, 1999 and November 19, 1999.

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EXECUTIVE SUMMARY

The objective of the ATS program is to develop ultra-high efficiency, environmentally superior and cost competitive gas turbine systems for base load application in utility, independent power producer and industrial markets. In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plants is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design. This report summarizes Phase III activities for the three month period January 1, 2001 to March 31, 2001.

Phase 3 extension originally involved no load testing of the ATS turbine generator. A redefinition of Phase 3 extension tasks was submitted as a continuing application to the Department of Energy on March 31, 1999. The continuing application continues to focus on critical engineering, manufacturing, development and testing to verify the readiness of ATS technology for commercial application. Approval of the continuing application was received in June 1999. A second continuation application was submitted in November 1999.

Further investigation of the new combustion rig revealed additional damage. The transition piping was cracked, the vane simulator cylinders were damaged and there are cracks in the exhaust duct support. All of these items are in process of being repaired and testing is scheduled to resume in February.

The turbine blade root verification testing is waiting for Hamilton to complete the broach machining of the test disc. The dummy blades have been sent to STC.

Negotiations continue with various vendors towards the development of a catalytic combustor. The test agreement with Catalytica has been signed and further negotiations towards a commercial agreement are scheduled for mid-April.

A second coating run was completed at Walbar on a full scale ATS transition. Thickness measurements results on cut outs from the transition show improvement in the coating thickness from an average of 0.9 mils after run 1 to 1.2 mils after run 2.

The mechanical test results from a low zirconium / low boron content heat of IN-939 was received from Cincinnati Test Labs. The results were in line with previously measured trends and provided an important data point for low alloy content IN-939. The creep resistance of this alloy was very poor and did not meet SWPC requirements for IN-939, as predicted by our previous data for higher Zr and B content heats.

High flux rig testing of APS TBC (MARM002 material and RT122 bond coat) at 2200ºF surface temperature revealed that after a certain dwell time (about 1 hour) the time to failure stays constant with dwell time (tested up to 8 hours). There appear to be two different mechanisms in

action, one below one-hour dwell time and one above. This finding shows that in future tests one-hour dwell times will be sufficient (thus saving time and money).

At STC, JHU successfully obtained the first through-transmission Laue image from a small turbine blade sample (approximately 3" long) that SWPC provided earlier. Next, JHU will try even higher radiation sources (MeV range) to develop a technique for larger blades and vanes.

Testing to assess the effect of strain ratio and coating on the low cycle fatigue properties of IN939 at temperatures of 800 and 900°C with a strain range of 0.5% and hold times of up to 300 seconds is almost complete.

Purchase orders have now been issued to all of the vendors necessary to provide the machining work for the row 1 vane. The initial work will be done on conventionally cast cobalt alloy vanes with the intent of testing in the hot cascade rig. PCC has processed casting trial 4. The problem of mold run-out has yet to be resolved.

Preliminary study results describing the application of the ATS turbine in coal-fueled applications were presented to DOE/NETL as part of a related briefing in Pittsburgh in early March. The draft topical report has been revised and internal review of the report is continuing.

Negotiations with PCI on a long-term development agreement have ended unsuccessfully. Major differences included exclusivity of the technology and manufacturing. SWPC still has rights to the technology per the agreement, which expired in October, so we will continue to develop it without PCI. Coated tubes for Module #3 were received from PCI and are being instrumented and installed. Module #3 should be completed by the end of April.

INTRODUCTION

BACKGROUND

The National Energy Strategy (NES) calls for a balanced program of greater energy efficiency, use of alternative fuels, and the environmentally responsible development of all U.S. energy resources. Consistent with the NES, an U.S. Department of Energy (DOE) program has been created to develop Advanced Turbine Systems (ATS). The Siemens Westinghouse ATS Program is funded and directed by DOE's National Energy Technology Laboratory (NETL). The technical ATS requirements are based upon two workshops held in Greenville, SC that were sponsored by DOE and hosted by Clemson University. The objective of this 8-year program, managed jointly by DOE's Office of Fossil Energy, and, Office of Conservation and Renewable Energy, is to develop natural-gas-fired base load power plants that will have cycle efficiencies greater than 60%, lower heating value (LHV), be environmentally superior to current technology, and also be cost competitive. The program will include work to transfer advanced technology to the coal- and biomass-fueled systems being developed in other DOE programs.

METHODOLOGY

The Advanced Turbine Systems program is structured into four elements:

- Innovative Cycle Studies
- Utility Advanced Turbine Systems
- Industrial Advanced Turbine Systems
- Technology Base

Within each program element there are several planned phases. For example, the Innovative Cycle Studies element includes two phases.

- Program Definition/Planning Studies
- Concept Development

The objective of the ATS Program is to develop ultra-high efficiency, environmentally superior, and cost-competitive gas turbine systems for base-load application in utility, independent power producer, and industrial markets. Specific performance targets have been set using natural gas as the primary fuel:

- System efficiency that will exceed 60% [lower heating value basis (LHV)] on natural gas for large-scale utility turbine systems; for industrial applications, systems that will result in a 15% improvement in heat rate compared to currently available gas turbine systems.
- An environmentally superior system that will not require use of post-combustion emissions controls under full-load operating conditions.
- Busbar energy costs that are 10% less than current state-of-the-art turbine systems, while meeting the same environmental requirements.
- Fuel-flexible designs that will operate on natural gas but are also capable of being adapted to operate on coal-derived or biomass fuels.
- Reliability-Availability-Maintainability (RAM) that is equivalent to the current turbine systems.
- Water consumption minimized to levels consistent with cost and efficiency goals.
- Commercial systems that will enter the market in the year 2000.

In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plants is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design. Phase 3 extension activities focus on critical engineering, manufacturing development, and testing to verify the readiness of ATS technology for commercial applications.

This report summarizes Phase III extension activities for a three month period. Additional details may be found in monthly technical progress reports covering the period stated on the cover of this report. Background information regarding the work to be completed in Phase III may be found in the revised proposal submitted in response to A Request for Extension of DE-FC21-95MC32267, dated May 29, 1998 and the Continuing Applications of DE-FC21-95MC32267, dated March 31, 1999 and November 19, 1999.

RESULTS AND DISCUSSION

11.0 PROGRAM MANAGEMENT

There were no scheduled activities for this quarter.

12.0 DEVELOPMENT ENGINEERING

12.1 VERIFICATION TESTS

Vane Cascade Further investigation of the new combustion rig revealed additional damage. The transition piping was cracked, the vane simulator cylinders were damaged and there are cracks in the exhaust duct support. All of these items are in process of being repaired and testing is scheduled to resume in February. Agilis completed the vane cascade component design work and presented a final design review to SWPC. The review revealed that the specified life-cycle for the components was unacceptable. Also the exhaust duct back wall had excessive deflection and additional design details for the side wall vane trailing edge feather seals is needed. An overall material change is being considered and additional analysis will be done on the critical components.

Turbine Root Blade Verification Hamilton has estimated the final machining to complete in the April/May time frame. All of the dummy blades have been shipped to STC in Pittsburgh.

Turbulator Model Tests No scheduled progress to report.

12.2 C. T. ENGINE DEVELOPMENT ENGINEERING

Combustion System Development Continued negotiations with various vendors towards the development of catalytic combustion. The test agreement with Catalytic has been signed and further negotiations towards a commercial agreement are scheduled for mid-April. Preparations for testing the Catalytica module at DLR are in progress. The high inlet air temperature requirement forces the use of the larger test bay. In order to mate to the existing Catalytica module design, a new rig configuration will be required. Testing has been scheduled for September.

Advanced Seal Development

Rope Seal No scheduled progress to report.

Brush Seal Development Program is complete.

12.3 MATERIALS DEVELOPMENTAL ENGINEERING

Steam Effects on Materials A second coating run was completed at Walbar on a full scale ATS transition. Thickness measurements results on cut outs from the transition show improvement in the coating thickness from an average of 0.9 mils after run 1 to 1.2 mils after run 2. Further analysis of the coating quality is ongoing. STC has reviewed the bonding fixture and approved for purchase. Machining of samples is ongoing.

Advanced Vane Alloy The mechanical test results from a low zirconium / low boron content heat of IN-939 was received from Cincinnati Test Labs. The results were in line with previously measured trends and provided an important data point for low alloy content IN-939. The creep resistance of this alloy was very poor and did not meet SWPC requirements for IN-939, as predicted by our previous data for higher Zr and B content heats. The new test data will be used to support a revision of PDS 15119Z4 to tighten the allowable range of minor alloying element additions. Two specimens from the previous group of modified IN-939 heats were given an additional heat treatment, identical to the pre-weld heat treatment currently applied to W501G IN-939 vanes, and were tested for weldability by Oak Ridge National Lab. The results indicated that the additional heat treatment was not effective in increasing the weldability of these specimens, as measured via the Sigmajig weldability test

TBC Life Prediction High flux rig testing of APS TBC (MARM002 material and RT122 bond coat) at 2200ºF surface temperature revealed that after a certain dwell time (about 1 hour) the time to failure stays constant with dwell time (tested up to 8 hours). There appear to be two different mechanisms in action, one below one-hour dwell time and one above. This finding shows that in future tests one-hour dwell times will be sufficient (thus saving time and money). At TBC surface temperatures lower than 2200ºF, there is an interaction between TBC surface temperature and bond coat temperature in the TBC lifing considerations.
With APS coating, the allowable bond coat temperature can be as high as 1830ºF for acceptable coating life (providing that the TBC surface temperature is maintained below 2050ºF). Because EB-PVD TBC has lower tolerance for application process inconsistencies, its bond coat temperature cannot go as high as 1830ºF.

ATS NDE As part of developing X-ray diffraction technique (through-transmission Laue) for the inspection of single crystal blades and vanes, Johns

Hopkins University (JHU) visited SWPC's STC facility to use their high power radiation source (Siefert Isovolt 320keV/13mA) which is much larger unit than JHU's current 50keV/32mA unit. At STC, JHU successfully obtained the first through-transmission Laue image from a small turbine blade sample (approximately 3" long) that SWPC provided earlier. Next, JHU will try even higher radiation sources (MeV range) to develop a technique for larger blades and vanes.

TMF testing row 1 blade alloy Testing to assess the effect of strain ratio and coating on the low cycle fatigue properties of IN939 at temperatures of 800 and 900°C with a strain range of 0.5% and hold times of up to 300 seconds is almost complete. TMF testing of IN939 has started and progressing to plan. Testing will continue throughout the first quarter of 2001.

Ring Segment Abradable Coating Development No scheduled activities this quarter.

Alternate Alloy Development No scheduled activity this quarter.

Liquid Metal Cooling Casting N*o* scheduled activity this quarter.

12.4 C. T. MANUFACTURING ENGINEERING

Row 1 Blade and Vane Alternative Design Purchase orders have now been issued to all of the vendors necessary to provide the machining work for the row 1 vane. The initial work will be done on conventionally cast cobalt alloy vanes with the intent of testing in the hot cascade rig. PCC has processed casting trial 4. The problem of mold run-out has yet to be resolved. The inputs for casting trial 5 are in process which will only be 2 molds of the airfoils and should be ready to pour by the end of April. Alloy samples have been machined for use in the welding evaluation trials. The samples should be welded and ready for analysis by the end of February

12.5 GENERATOR DEVELOPMENTAL ENGINEERING

ATS Class G Stator Development. No scheduled activity.

12.6 ADAPTATION TO COAL AND BIOMASS FUELS

Preliminary study results describing the application of the ATS turbine in coal-fueled applications were presented to DOE/NETL as part of a related briefing in Pittsburgh in early March. The draft topical report has been revised and internal review of the report is continuing.

13.0 C. T. MANUFACTURING DEVELOPMENT AND TOOLING

13.1 DELETED

13.2 MANUFACTURING & TOOLING DEVELOPMENT ENGINEERING

No scheduled activity.

13.3 DELETED

13.4 MANUFACTURING VERIFICATION TESTS

No scheduled activity.

14.0 ATS TECHNOLOGY VERIFICATION PROGRAM

14.1 STEAM COOLED COMPONENT & AERO-THERMAL DESIGN VALIDATION TEST

Task is complete.

14.2 ADVANCED VISCOUS COMPRESSOR TEST

Task is complete.

14.3 CATALYTIC COMBUSTOR TEST

Negotiations with PCI on a long-term development agreement have ended unsuccessfully. Major differences included exclusivity of the technology and manufacturing. SWPC still has rights to the technology per the agreement, which expired in October, so we will continue to develop it without PCI. Mechanical design of the modules is continuing. The main thing we lose without PCI is the catalytic coating itself. We have initiated discussions with several other coating vendors to acquire coating samples for testing.

Manufacturing of Modules # 3 and #4 is continuing. Coated tubes for Module #3 were received from PCI and are being instrumented and installed. Module #3 should be completed by the end of April. Module #3 testing has been moved from Solar to GASL due to a Solar compressor problem. Testing is scheduled for mid-May. A peer review was held on the ATCC3 combustor conceptual design. The biggest concern was vibration of the parts (both catalytic and non-catalytic). Shaker table tests are being planned to resolve the concerns. Several coating vendors have supplied catalytic coating samples for testing at Penn State. Penn State has started the testing and should have initial results by the end of April

14.4 STEAM COOLED VANE TEST

No scheduled activity.